N64-15869

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AN EXAMPLE OF A REUSABLE EARTH-LUNAR TRANSPORTATION SYSTEM

BY

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HUNTSVILLE, ALABAMA

Presented PAPER DELIVERED TO THE AIAA SUMMER MEETING, Los Angeles
AMBASSADOR HOTEL, LOS ANGELES, CALIFORNIA

JUNE 1963

ABSTRACT

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This paper discusses a lunar transportation system utilizing reusable vehicles throughout the mission. The vehicle concepts discussed are based on feasibility and conceptual design studies performed by industry for the Future Projects Office, George C. Marshall Space Flight Center.

The concepts discussed are <u>not</u> approved programs of NASA, nor does this paper infer that these systems will become approved programs. However, it attempts to show the advantages that such concepts might offer to the lunar transportation mission if they become available. Author

INTRODUCTION

During the past few years many studies have been conducted by industry and agencies of the government on reusable space vehicles. These studies have concentrated on Earth launch vehicles and their design and operational trade-offs in terms of performance, availability, and cost effectiveness. Recent studies have investigated other phases of space travel for specific missions, e. g., lunar transportation. However, these studies have usually been limited to one phase of operation such as Earth to Earth orbit, Earth escape, Earth orbit to lunar orbit, etc. The remaining work to be done is an integration of the promising design concepts for these separate and special applications into an overall transportation system.

This paper will consider a reusable transportation system for transporting personnel and cargo to and from a lunar base. This paper will not be concerned with the detailed design of the separate elements of the systems, their feasibility, their development cost, or the operational trade-offs that determined the designs. These subjects are covered in the references and in other papers of this session authored by people who have been engaged in this detailed analysis work.

The approach here will be to determine the cost of a lunar man-year assuming the vehicle systems discussed become available. The lunar base size that can be supported by this system, given certain funding levels for lunar activities, can be readily seen from the results.

The mission has been broken down into phases of operation, and each phase analyzed over a spectrum of cost conditions to determine their individual effect on the total cost. Included in the cost is the payload required to support the man during his staytime at the base; the vehicles have been designed to include this requirement.

MISSION DESCRIPTION

Before describing the particular mission this paper is concerned with, it might be advantageous to discuss how or why this concept evolved. Of course, NASA is continuously looking for more economical means of performing the space missions, and past studies have resulted in certain trends and philosophies. The studies performed to date indicate that reusable systems are needed in order to get an order of magnitude improvement in cost. Figure 1 shows an analysis of the trends in transportation cost done by Mr. Koelle about a year ago (Ref. 1). This figure shows the early APOLLO cost and its limited improvement with time due to learning. By introducting a more efficient landing and return system based on high energy propellants, there is some cost improvement. The next step might be to add a nuclear escape stage to the expendable launch vehicle which would result in increased efficiency. Resuable vehicles are introduced next, first in the Earth to orbit phase and then into the total mission. It is the latter area that this paper will discuss in more detail.

Figure 2 shows schematically the mission profile of the lunar transportation system analyzed in this paper. For this discussion, the mission is broken down into the following phases:

1. Outbound phase consisting of: Earth surface to Earth orbit; Earth orbit to lunar orbit; lunar orbit to lunar surface.

2. Inbound phase consisting of: lunar surface to lunar orbit; lunar orbit to Earth orbit; Earth orbit to Earth surface.

The return is mentioned to emphasize that the personnel are returned to Earth through orbit instead of re-entry at parabolic speeds as with the APOLLO. This allows a limited environment of 2 - 3 g's for the total mission, and permits personnel with special skills, who do not have astronaut qualifications to man the lunar base.

VEHICLE CONCEPT DESCRIPTION

For each of these phases of operation, there are reusable vehicle concepts that are desirable from a most economical system standpoint. These concepts are obvious, perhaps, but are reiterated for emphasis:

1. Earth surface to Earth orbit vehicle which has a limited "g" mission profile for 10 passengers.

2. Earth surface to Earth orbit cargo and tanker vehicle for servicing the orbital launch vehicle.

3. Earth orbit to lunar orbit and return vehicle for cargo and personnel; designated the reusable nuclear ferry vehicle in this paper.

4. Lunar orbit to lunar surface vehicle; designated the lunar shuttle vehicle in this paper.

The other papers in this session and the references present more detailed information on these vehicle concepts. The concepts are mentioned here to describe the general type of vehicle that have been considered in studies to date.

Figure 3 shows a concept for the 10 passenger transport being studied by Lockheed (Ref. 2) and North American Aviation. This concept is a two stage winged vehicle using a parallel staging arrangement. It is a horizontal take-off and landing vehicle with both stages recoveralbe. Other concepts using tandem staging, separate payload stage, vertical take-off, etc., have been studied, but at present the vehicle illustrated is one of the most promising concepts. The general physical characteristics of the vehicle are: 15-foot diameter, 125-foot wing span, 110-foot length, and 1.5 million pounds gross weight. The vehicle uses advanced F-1 first stage propulsion and two modified J-2 engines or an advanced high chamber pressure engine in the second stage.

Figure 4 shows a concept for the reusable cargo-tanker vehicle conceived by General Dynamics/Astronautics and called NEXUS (Ref. 3). It will deliver approximately 1.0 million pounds into Earth orbit.

The NEXUS is a single stage vehicle weighing around 24 million pounds, is 160 feet in diameter, 380 feet long, and has a plug nozzle propulsion system with a thrust of about 30 million pounds.

Figure 5 is another concept designed for this mission by Douglas Aircraft Company and called Rhombus (Ref. 4). It consists of a single tank main stage with eight hydrogen tanks which are staged in pairs during the trajectory. It also delivers about 1.0 million pounds of payload to orbit. The gross weight of the Rhombus is approximately 14 million pounds; it has a diameter of 80 feet, a length of 270 feet, and has a plug nozzle propulsion system that develops around 20 million pounds of thrust.

Figure 6 is a nuclear ferry vehicle concept designed by The Martin-Marietta Corporation (Ref. 5). It will deliver 20 passengers plus 80,000 pounds of cargo to the lunar orbit in addition to the propellant required to operate the shuttle vehicle. The vehicle is about 200 feet long, 33 feet in diameter, weighs 800,000 pounds at launch from orbit, and has an advanced nuclear propulsion system that develops 170,000 pounds of thrust. The payload section consists of two cargo modules and a crew compartment.

Figure 7 is a chemical shuttle vehicle which is compatible with the nuclear ferry concept just described. It is 33 feet in diameter, 28 feet long, weighs about 250,000 pounds, and has a propulsion system consisting of one J-2 and two RL-10 engines.

SYSTEM ASSUMPTIONS AND ANALYSIS

Recent studies on the vehicle concepts described have indicated certain expected cost parameters for each system. Because of the uncertanity of these costs, they are expressed in terms of expected or reasonable maximum and minimum values. These assumptions or best estimates and other pertinent data, such as number of reuses, which are required for the analysis are presented below. The cost to Earth orbit for the personnel and cargo vehicles include their refurbishment and replacement cost. The range of cost for the ferry and shuttle reflect both uncertainty in the estimate as well as different degrees of refurbishment.

The measure of effectiveness or analysis criteria used for this paper is the cost per man-year on the Moon, or the cost to deliver and sustain one man on the moon for one year and return him to Earth. An important point is the fact that a ferry delivers, in one trip, 20 passengers with enough cargo to sustain them for 6 months. Therefore, the cost of each ferry trip is equivalent to 10-man years. This is used to arrive at the following expression for the cost of a man-year:

$$\text{Cost/Man-Year} = \frac{\text{Cost/Ferry Mission}}{\text{10-Man Years/Mission}}$$

where:

$$\text{Cost/Ferry Mission} = (\text{Wt in orbit})(\text{Del. Cost}) + (\text{No. Passengers})(\text{Del. Cost}) + \frac{\text{Ferry Cost}}{\text{Reuses}} + \frac{\text{Shuttle Cost}}{\text{Reuses}}$$

Cost assumptions are as follows:

1. Payload Cost to Earth Orbit = 25, 50, 75 dollars/pound
2. Passenger Cost to Earth Orbit = 100, 200 thousand dollars/man
3. Nuclear Ferry Unit Cost = 25, 50 million dollars
4. Nuclear Ferry Reuses = 10
5. Lunar Shuttle Unit Cost = 10, 15 million dollars
6. Lunar Shuttle Reuses = 10

DISCUSSION OF RESULTS

The first step in analyzing the system was to determine the cost of delivery to Earth orbit of personnel, their cargo requirement, and the propellant for the ferry and shuttle. Figure 8 shows this cost of delivery by the two major transport systems discussed earlier using the cost of delivery of payload to orbit as the base point. A value was chosen for this cost and the minimum and maximum personnel delivery cost was added to determine the cost spectrum.

The cost values in Figure 8 were added to the other cost elements at their minimum and maximum values to develop the cost data in Figure 9. This shows the total cost spectrum; the actual cost could be anywhere within this range depending on the individual cost elements. The cross point indicates a best estimate of the value attainable in a reasonable time, as will be shown later.

To determine the sensitivity of total cost to the different elements of the transport system, the minimum and maximum cost lines were broken down into percentages of total cost and are shown in Figure 10. As would be expected, the cost of delivery to Earth orbit is the major contribution and ranges from 60 to 90 per cent with the personnel and ferry cost next in importance. It is in these areas that considerable effort is being directed in the Future Projects study program.

Figure 11 shows a possible trend in development of transportation systems that have application for a lunar mission. This figure shows the trends for manned systems in dollars/round trip and cargo delivery in dollars/pound.

Combining these costs, assuming a value for the payload required for the base operation, results in the lunar operations spectrum shown in Figure 12. Using this cost of operation, the maximum base size obtainable per billion dollars is shown. The cross point, corresponding to the best estimate point on Figure 9, indicates that such a system might be available in the early 1980's.

CONCLUSIONS

There are many points that influence the decisions affecting such a system that have not been mentioned in this paper. There is the important question of availability of the elements making up this concept, the selection of design concepts from the candidate systems, the funding requirements for development, and the mission requirements. One very clear point is that such a system is only attractive if there is a requirement for a large lunar base; this cannot be decided until more is known about the environment, and the missions for a lunar base are better defined. Depending on the missions of the lunar program, the development of all these systems may not be justifiable. ~~However,~~ since some systems obviously have application to other space programs, the lunar mission must be analyzed from the standpoint of the overall national program.

In conclusion:

1. Such a system is desirable for the transportation of large numbers of specially skilled personnel that will not have astronauts qualifications.

2. Such a system can give an order of magnitude improvement in direct operating cost over the present APOLLO system.

3. The system could be available in the early 1980's.

4. The two critical areas are nuclear propulsion, which is primarily a technological problem, and reusable Earth launch vehicles which for some concepts is a statement of requirement and funding problem.

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1. "On the Evolution of Earth-Lunar Transportation System," H. H. Koelle, Prepared for <u>From Peenemuende to Outer Space</u>, December, 1961.
2. "Conceptual Design of Reusable Ten-Ton Orbital Carrier Vehicle," Lockheed California Company, Contract No. NAS8-2687, January, 1963.
3. Advanced NOVA Launch Vehicle Study being conducted by General Dynamics/Astronautics under Contract No. NAS8-5022.
4. Advanced NOVA Launch Vehicle Study being conducted by Douglas Aircraft Company under Contract No. NAS8-5021.
5. "Study of an Advanced Lunar Transportation System," Final Technical Report No. ER12742, Martin-Marietta Corporation, Contract No. NAS8-1531, June, 1962 to December, 1962.

Figure 1. LUNAR ROUND-TRIP COST TRENDS

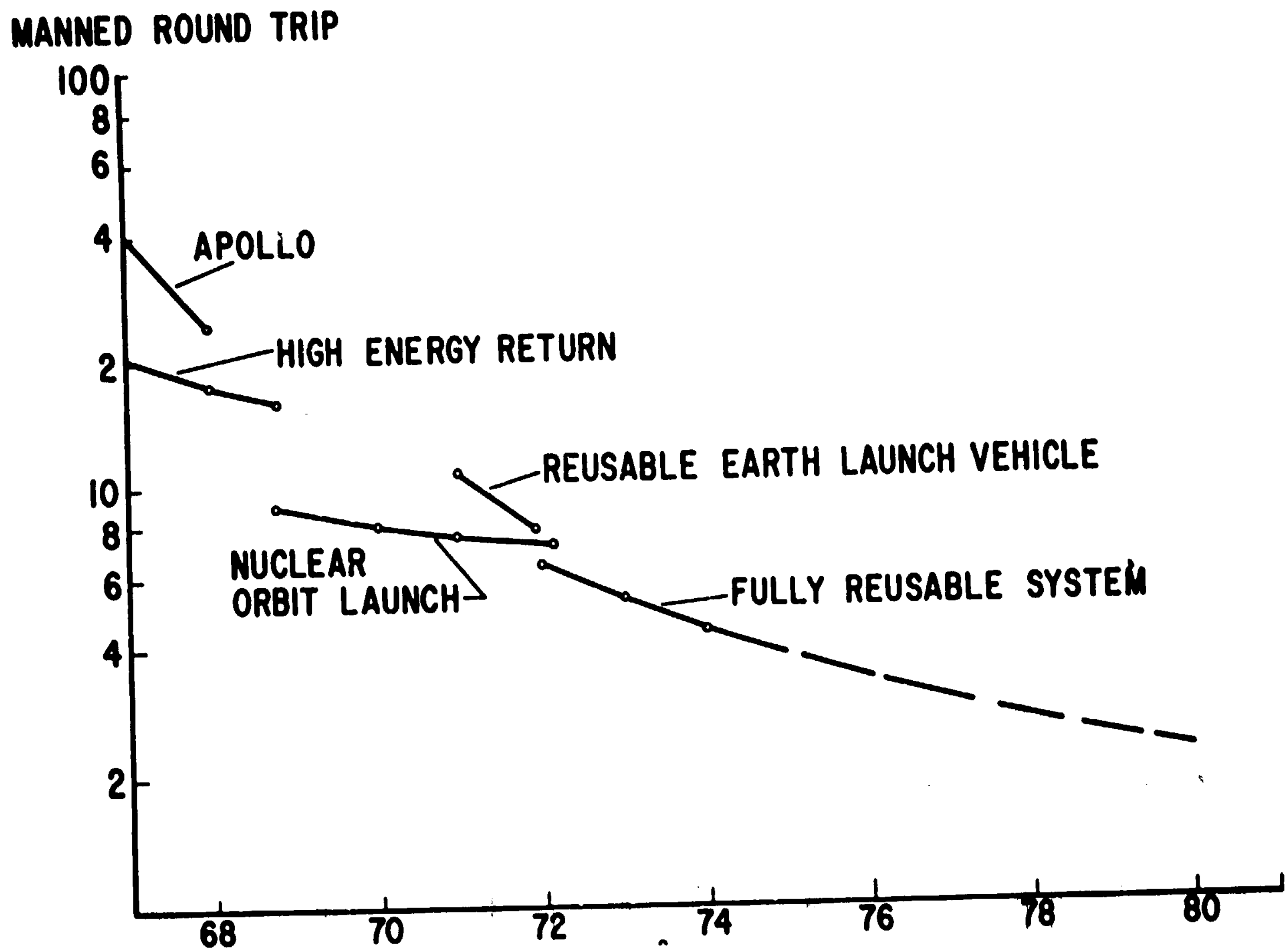

Figure 2.

REUSABLE NUCLEAR FERRY MISSION PROFILE

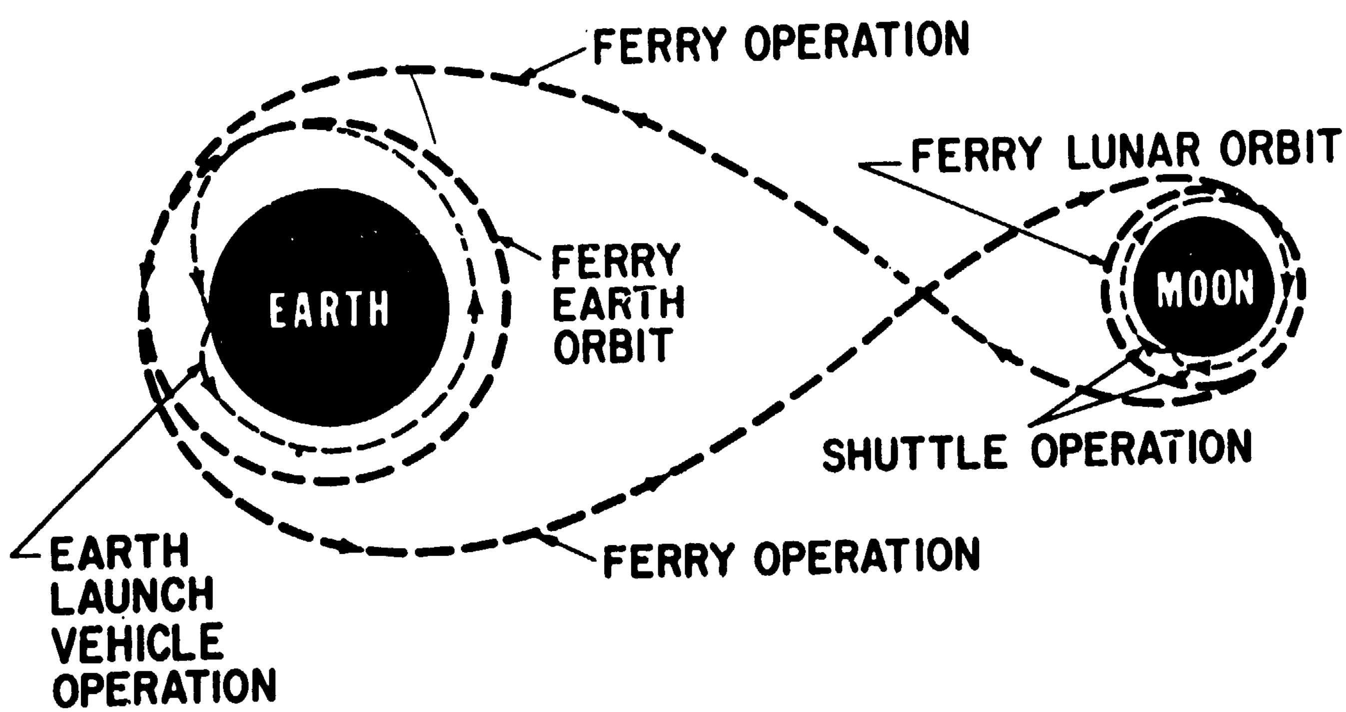

Figure 3. 10 PASSENGER REUSABLE ORBITAL FERRY VEHICLE

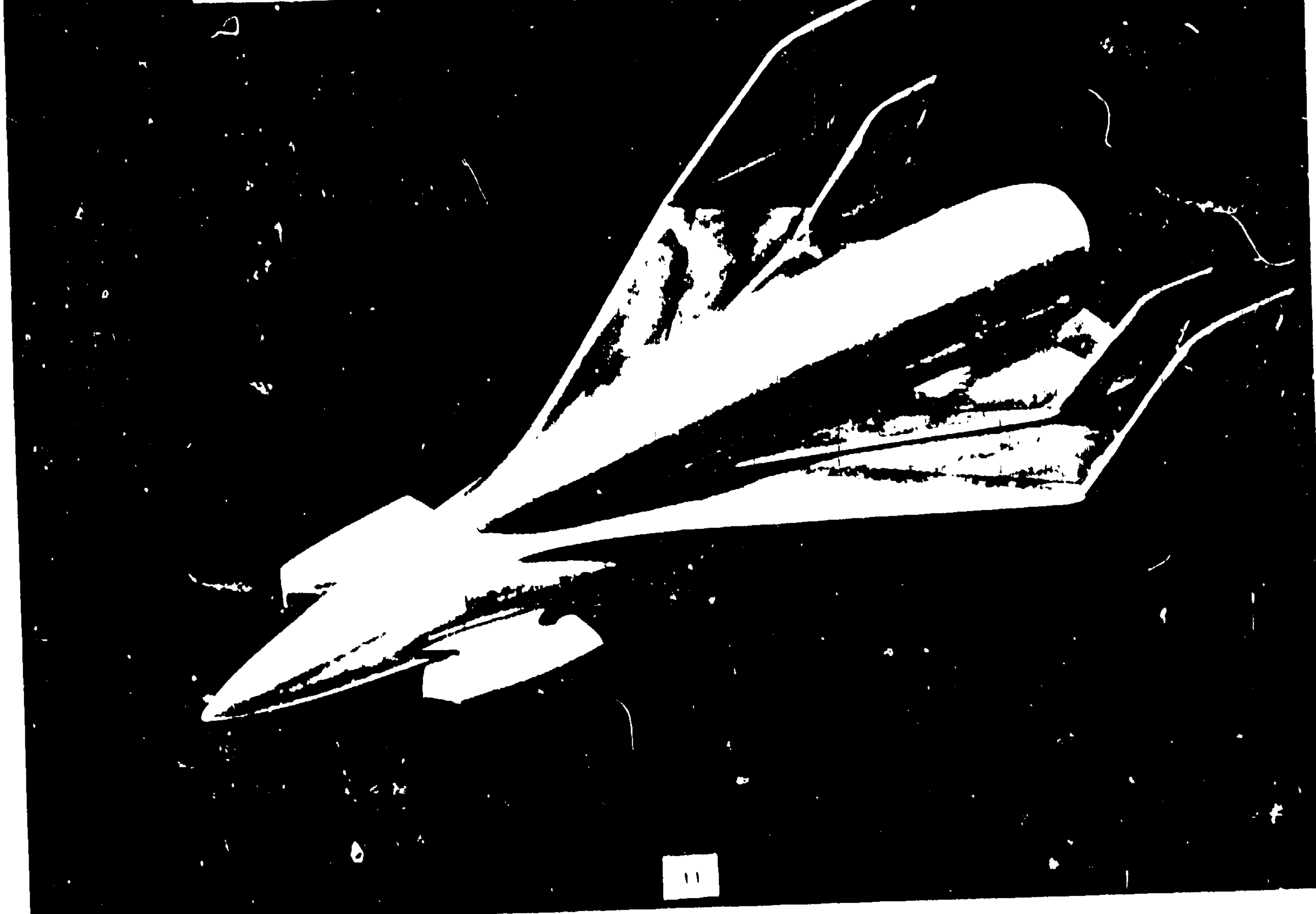

Figure 4. **SINGLE STAGE TO ORBIT**

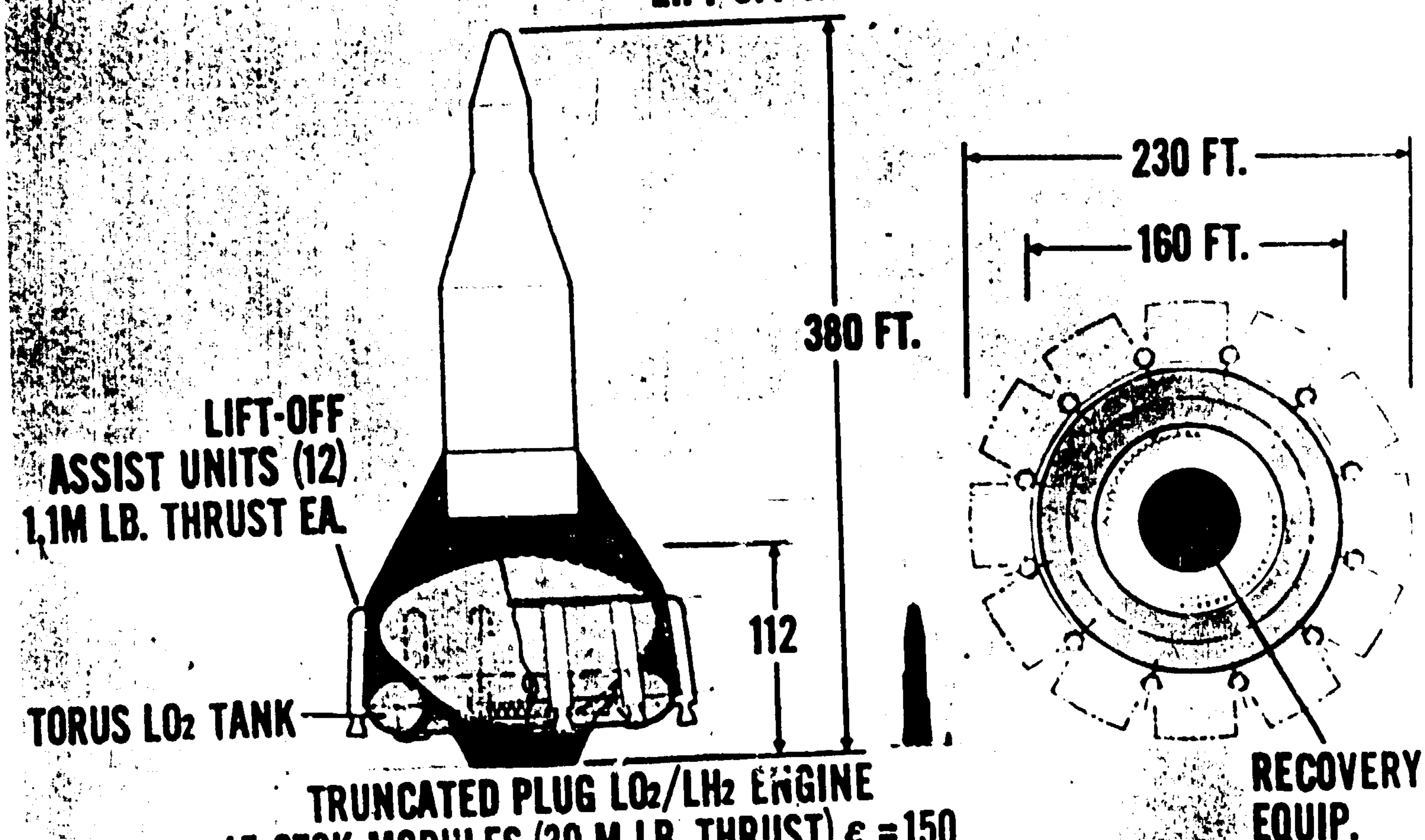

Figure 5. ROMBUS VEHICLE CONFIGURATION

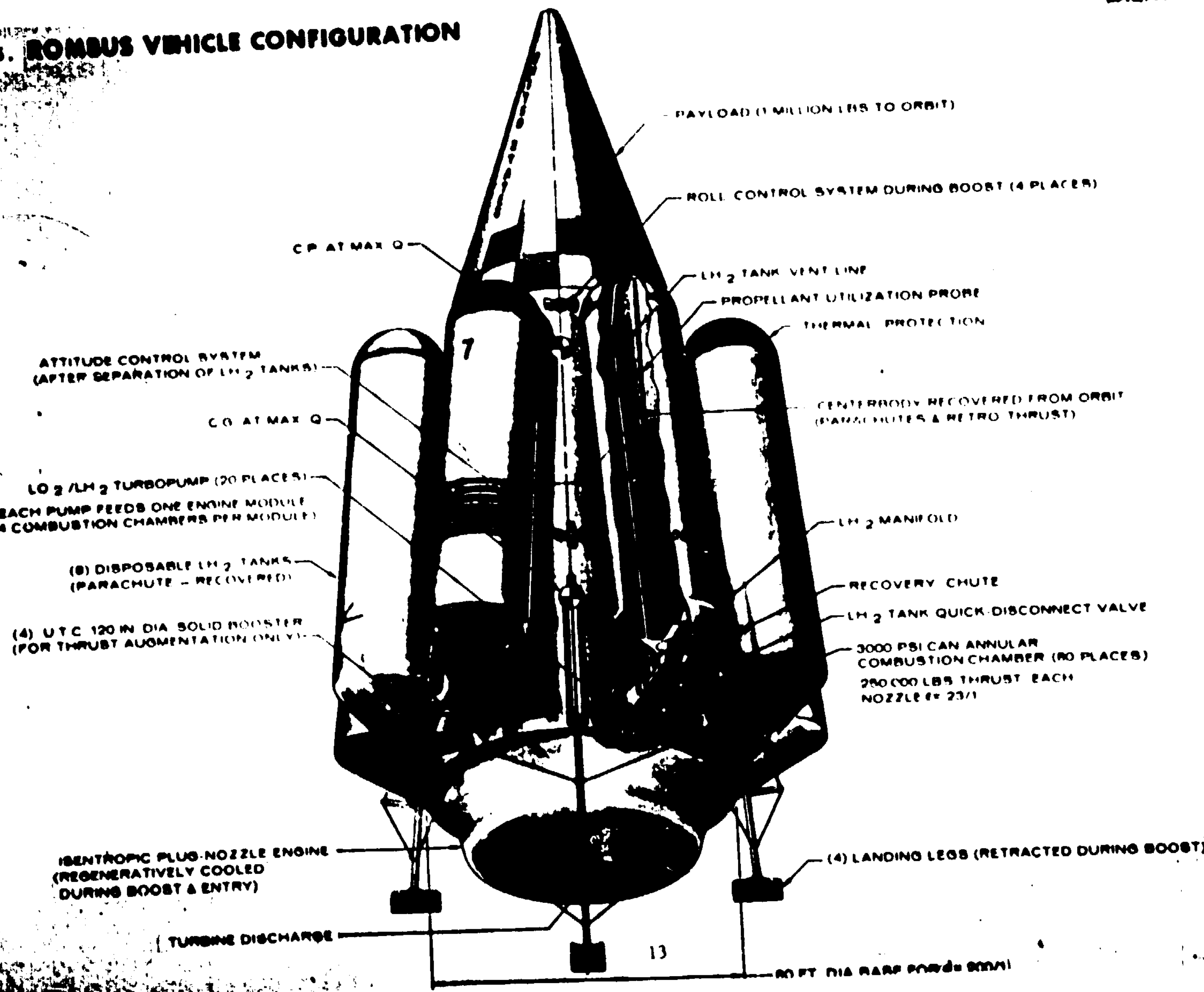

Figure 6. NUCLEAR FERRY VEHICLE

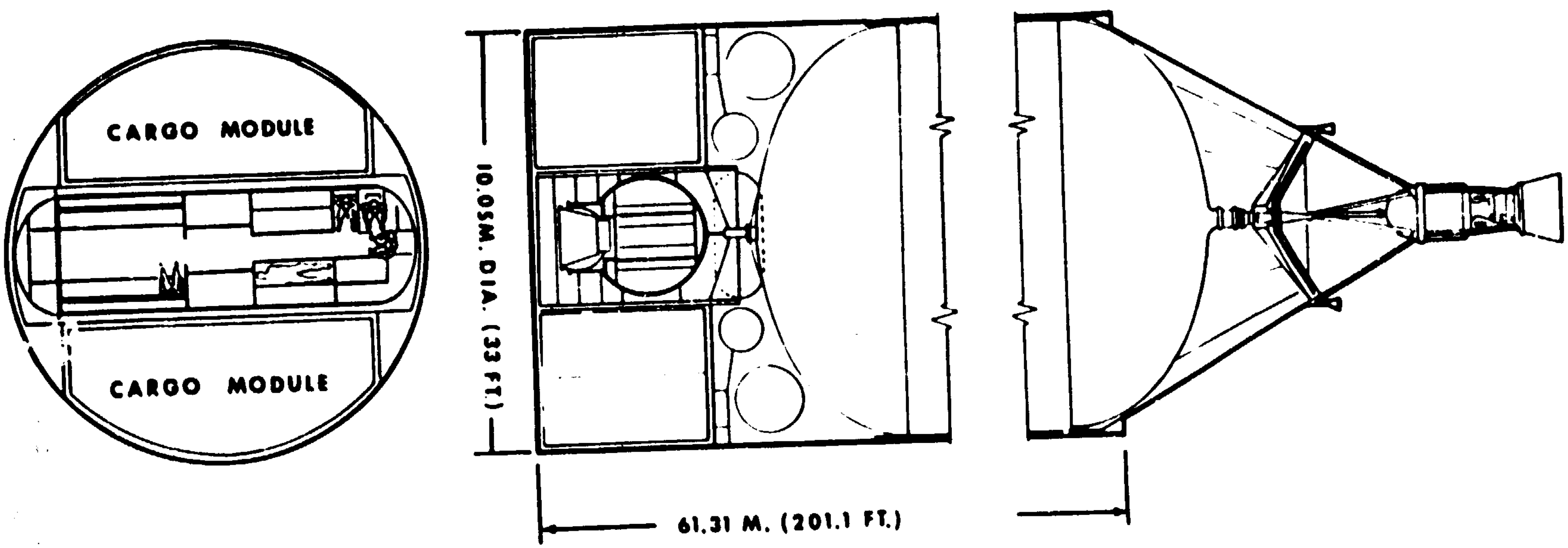

Figure 7.

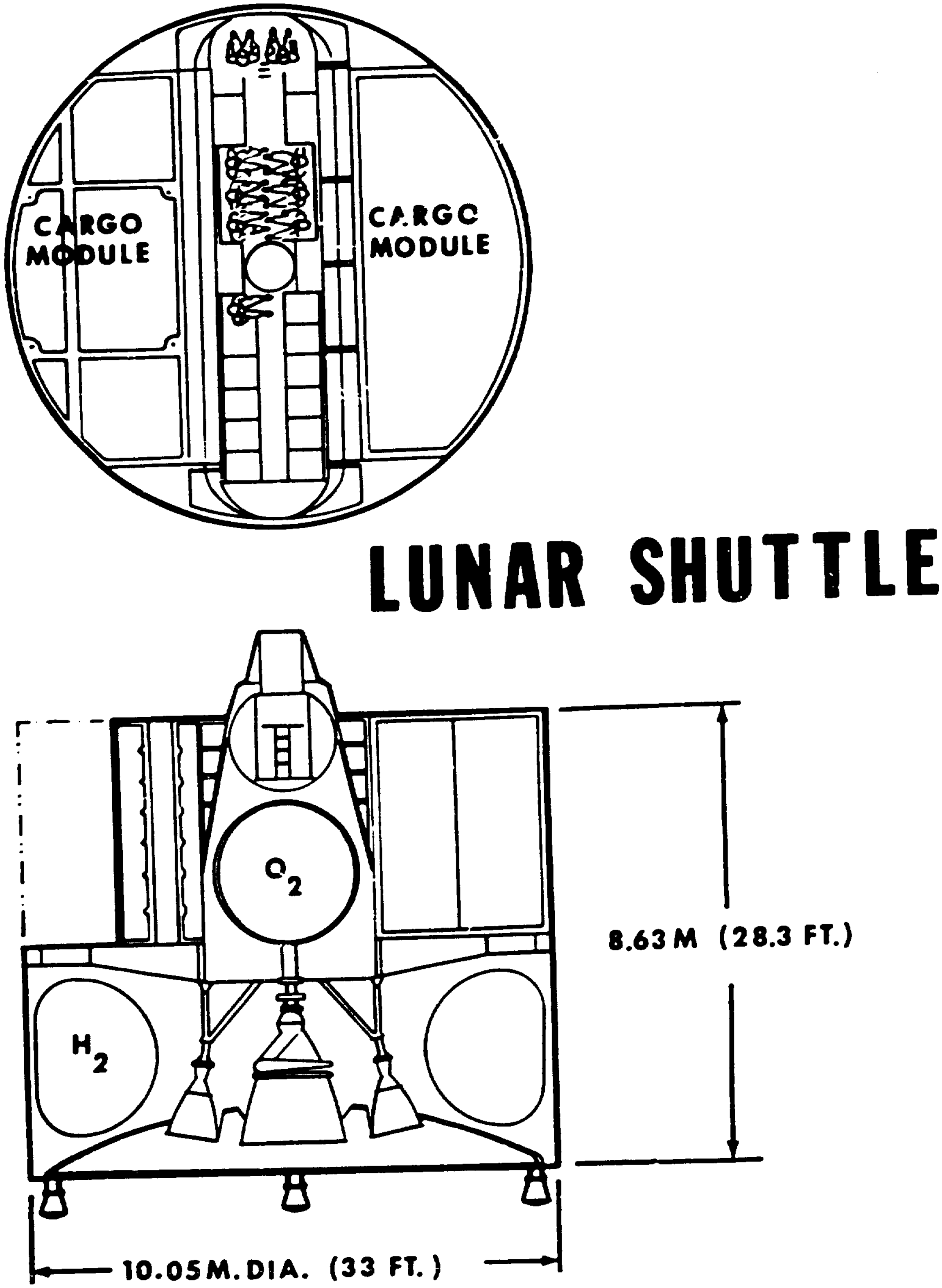
CARGO MODULE
CARGO MODULE
LUNAR SHUTTLE
O2
H2
8.63 M (28.3 FT.)
10.05 M. DIA. (33 FT.)

Figure 8. EARTH ORBITAL DIRECT OPERATING COST

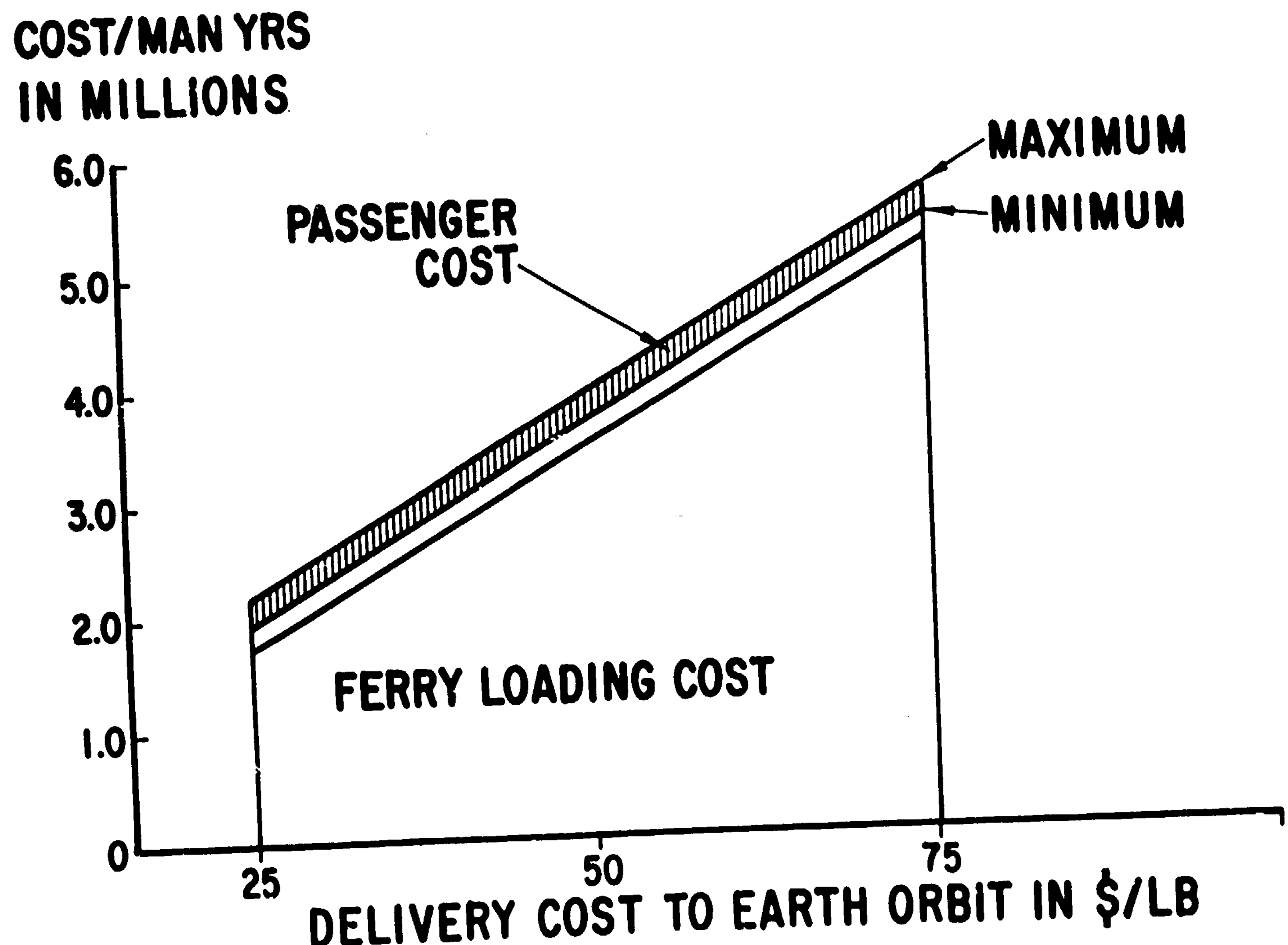

Figure 9. **TOTAL DIRECT OPERATING COST**

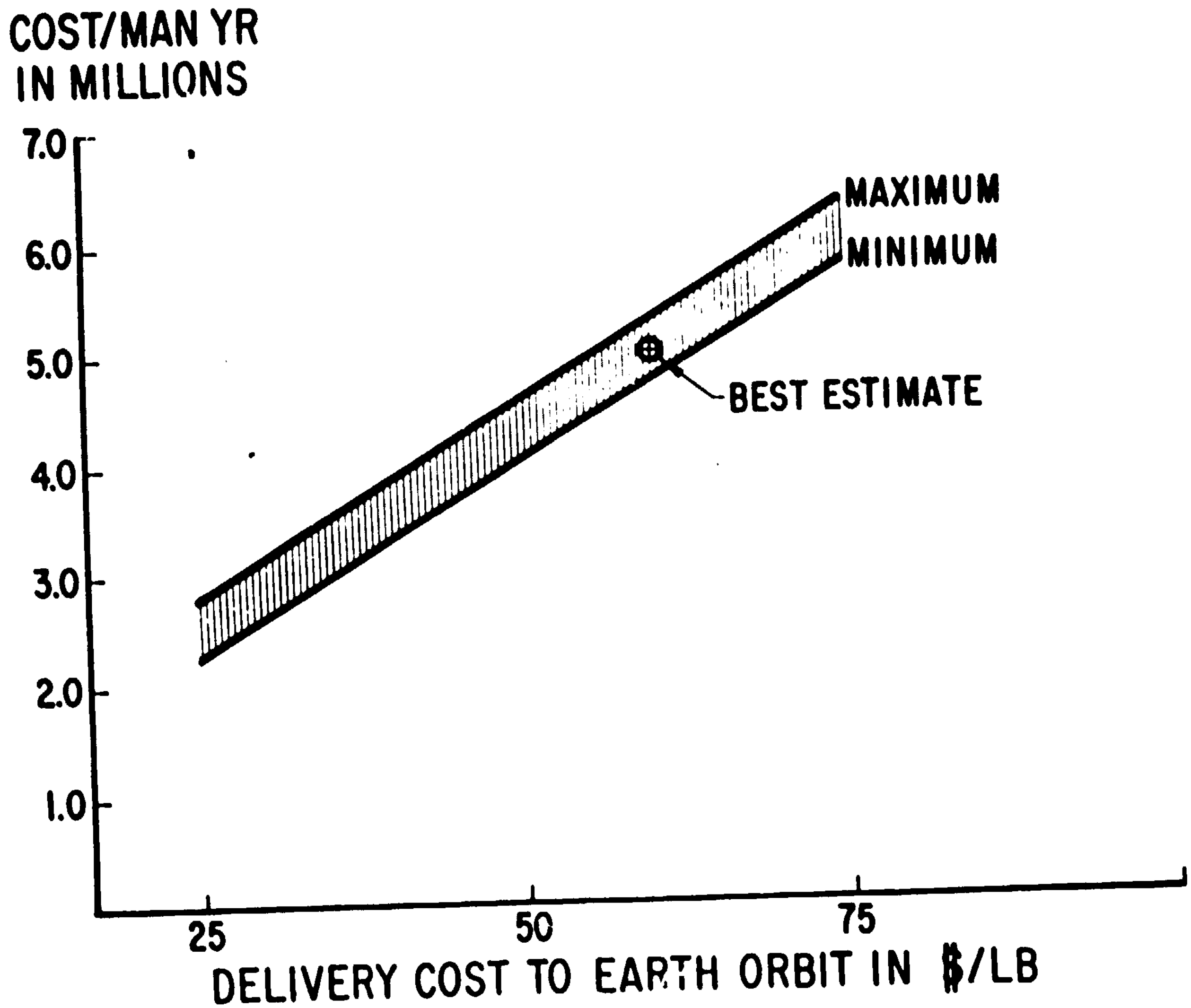

Figure 10. SENSITIVITY OF TOTAL COST TO INDIVIDUAL COST ELEMENTS

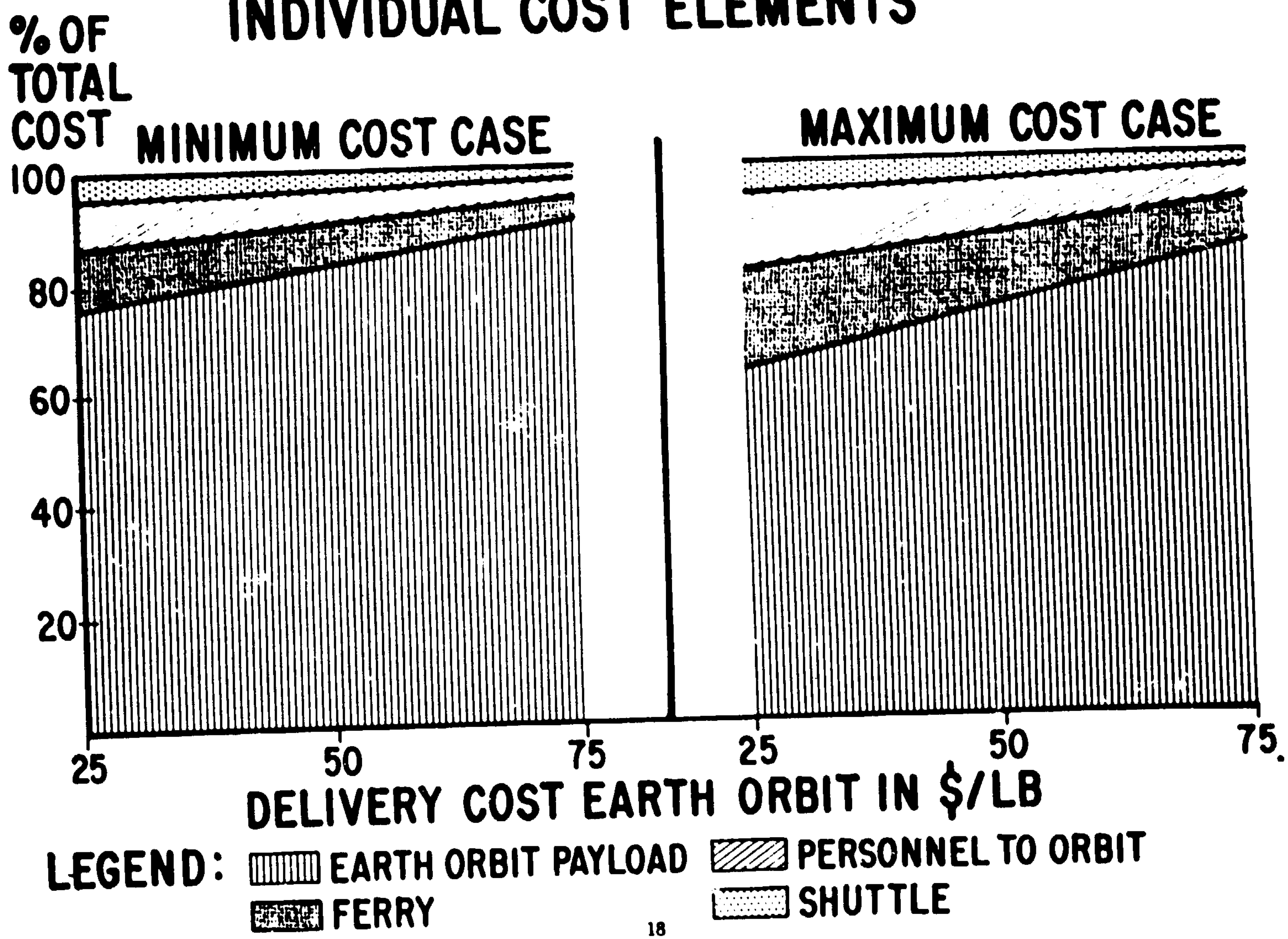

Figure 11. TRENDS IN DIRECT OPERATING COST FOR LUNAR TRANSPORTATION SYSTEMS

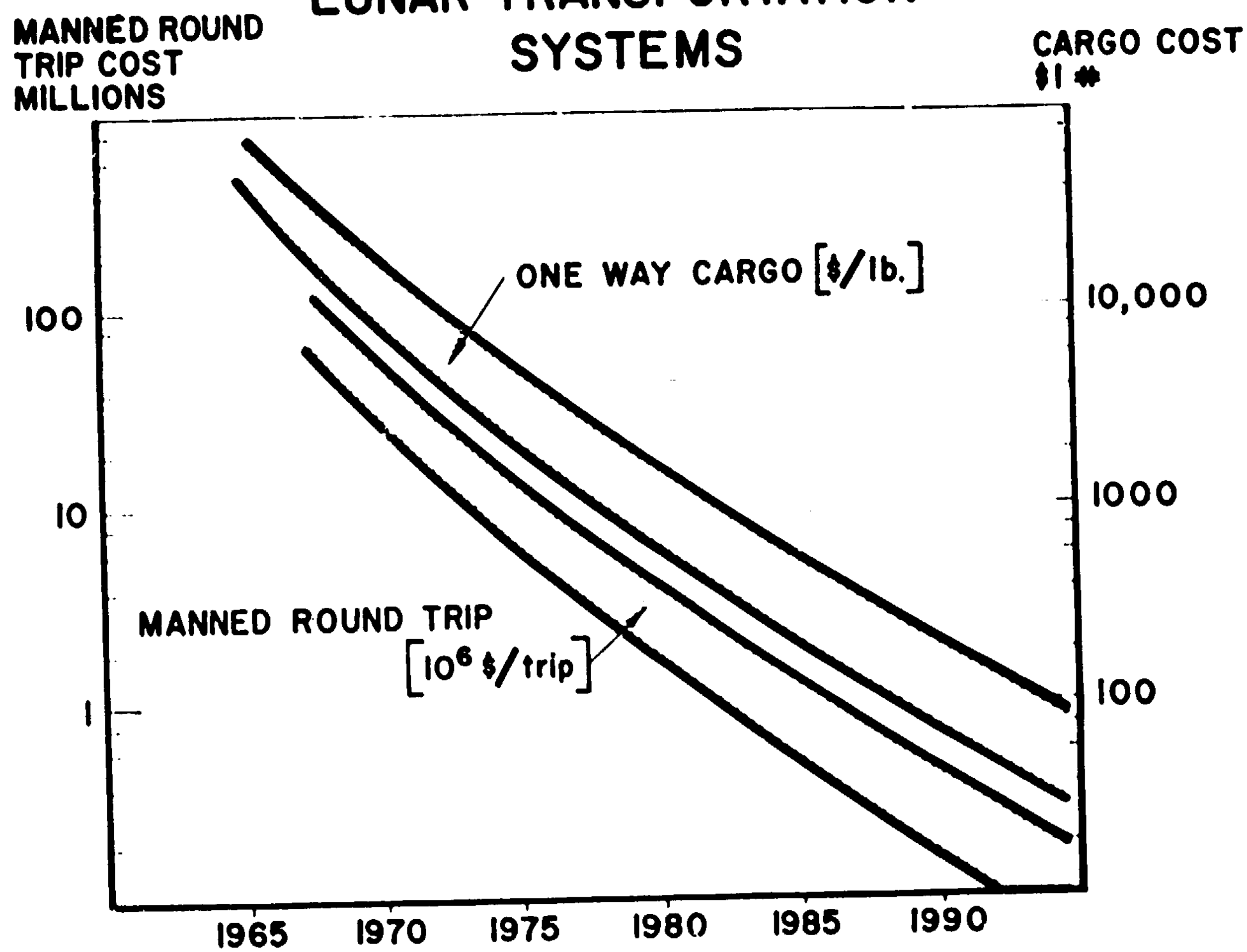

Figure 12.

TRENDS IN LUNAR OPERATING COST AND BASE SIZE